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# Economic Assessment of Photovoltaic Energy Production Prospects in India

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## Abstract

Over the past decade, the electricity generation landscape around the globe has changed severely with rapid multiplying of renewable generation. The 21<sup>st</sup> century has numerous points of power injection as well as millions of points of consumption. The power system in India has coarsely folded in the last decade and similarly in the previous decade. Alternative sources of energy are being sought after in the world today as the availability of fossil fuels and other non-renewable resources are declining. Photovoltaic energy offers an encouraging solution to this search as it is a less polluting renewable energy resource. The proposed work focuses on the Economic Assessment models while estimates the economic impacts of constructing and operating power generation at the local and state levels. The work considers many aspects of the problem including the energy and economic ones which is of basic importance for evaluating real outcomes of investments. The result of the assessment screens the economic feasibility of photovoltaic systems and the consequent production of electricity, recovering costs of installation and maintenance of the system. Additional economic aspects includes evaluation of costs of the PV systems (investment costs and costs for maintenance, servicing and insurance against damage) and benefits due to the gains for the avoided bill costs, the incentives and the sold electricity; analysis of cash flows; estimation of the energy cover factor related to the results of the economic analysis; sensitivity analysis for the most significant physical and economic parameter.

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**Keywords:** Photovoltaic Systems; Photovoltaic; Solar Potential; Urban Context; Energy Assessment; Economic Assessment; Energy

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## 1. Introduction

Photovoltaic (PV) systems provide electric energy and the range of uses for electricity and the situations in which it is employed are enormous. Moreover, there are numerous other well-developed

and widely used technologies for supplying electricity. Conventional fossil-fuel and hydroelectric generation are presently far more widely deployed than PV. The question arises then, of how PV systems can penetrate the world's electric supply in competition with these alternatives, or, more narrowly, how a PV system can compete with other electricity sources for a specified application[1]. PV is a rapidly developing technology with declining costs. The reason includes the economic benefits and the solar system's modularity, low maintenance, low noise level, long life and non-emission of greenhouse gases[2]. The combined modern and traditional renewable energy share remained about level with 2011, even as the share of modern renewables increased. This is because the rapid growth in modern renewable energy is tempered by both a slow migration away from traditional biomass and a continued rise in total global energy demand[3].

Over the past decade, the electricity generation landscape around the globe has changed severely – In the 20<sup>th</sup> century there were relatively few points of power generation or injection and millions of points of power consumption. With rapid proliferation of distributed and renewable generation, the 21<sup>st</sup> century will have numerous of points of power injection as well as millions of points of consumption. The power system in India has coarsely folded in the last decade and similarly in the previous decade. With 215 GW of installed capacity with utilities, the Indian power system is now the fourth leading in the world but per-capita consumption of electricity in India is only about one-fourth of the world average. This underscores the need to grow the power system at a rapid pace for the next several decades. The low consumption level is amplified by the lack of access in electricity to a significant proportion of the population.

Alternative sources of energy are being sought after in the world today, as the availability of fossil fuels and other non-renewable resources are declining. Solar energy offers a promising solution to this search as it is a less polluting renewable energy resource and can be easily converted into electricity through the usage of photovoltaic systems. The proposed work focuses on the Jobs and Economic Development Impact (JEDI) models that estimates the economic impacts of constructing and operating power generation and bio-fuel plants at the local and state levels[4]. First developed by NREL's Wind Powering America program to model wind energy impacts, JEDI has been expanded to analyse bio-fuels, coal, concentrating solar power, geothermal, marine and hydrokinetic power, natural gas, and photovoltaic power plants. The current work intends to evaluate the JEDI model for the issues concerning to urban energy and environment[5], [6].

The Jobs and Economic Development Impact (JEDI) models are user-friendly tools that estimate the economic impacts of constructing and operating power generation and bio-fuel plants at the local and state levels. First developed by NREL's Wind Powering America program to model wind energy impacts, JEDI has been expanded to analyse bio-fuels, coal, concentrating solar power, geothermal, marine and hydrokinetic power, natural gas and photovoltaic power plants[7]. A methodology that permits testing the level of integration of the photovoltaic technology in urban areas is presented. The percentage of electricity coverage demand of grid-connected photovoltaic systems installed on the roofs of the building was investigated.

#### **Nomenclature**

$C_{PV}$  energy cover factor [%]  
 $E_{PV}$  electricity produced by PV system [kWh]  
 $D_{Total}$  electrical energy demand [kWh]  
 $D_{day}$  day energy demand [kWh]  
 $D_{night}$  night energy demand [kWh]

## **2. Data and methods**

### *2.1. Study area*

India has an area of 3.29 Mio.km<sup>2</sup> and is the 7th biggest country in the world. Sharing borders with India are Bangladesh, Bhutan, Myanmar, China, Nepal and Pakistan[8]. Life forms from unicellular to Chenab multicellular and microscopic to gigantic sizes by the forests, deserts, Ravi mountains, other land, air and water provide shelter, food, medicine, fodder, fuel, clothing for our daily needs and raw material for industry.



Fig.1. Outline of study area

The Indo-Gangetic Plain occupies Chandigarh Dehradun most of northern, central, and eastern India while the Deccan Plateau Darjeeling occupies most of southern India. To the west of the country is the Thar Desert which consists of a mix of rocky and sandy desert. India's east and north eastern border consists of the high Himalayan range[9].

## 2.2. Methodology

The financial considerations in a decision to deploy PV can be quite different in developed regions than in the undeveloped regions. In a developed country, the economic units (e.g. individuals, families, businesses, government operations) have a cash flow and well-defined energy needs[10]. The question that they must answer periodically is what source of energy they will choose from among competing alternatives that are highly developed and more or less readily available. The question can be addressed in a quantitative fashion at varying levels of sophistication and the resources are available to implement the choice[11]. In undeveloped regions, the situation is more likely that the economic units are individuals or very small businesses with little or no cash flow. The question for these regions is whether any electric energy is at all affordable and where do the resources to pay for it come from. The purely financial comparison of electricity sources by private entities often becomes subservient to public economic-development initiatives and national and international politics may play a strong role. The choice of electric energy sources for the classes of applications must still be made and the cost of energy delivered in the sense employed for developed regions may still be computed but generally not by individuals or small economic units because they will not pay for them[1].

## 2.3. Economic analysis

Once the technical requirements of a PV application have been stated and a PV system design completed, the economic analysis can be carried out. The economic assessment includes both costs and benefits of the system. It considers many aspects of the problem including the energy and economic ones. Actually, even if it is important to evaluate the energy cover factor of a PV system, it could happen that the PV system does not harvest economic advantage from the operational phase. The combined analysis of energy and economic aspects is of basic importance for evaluating real outcomes of investments. To reach this result the proposed methodology follows the following economic aspects like[10]:

- a. evaluation of costs of the PV systems (investment costs and costs for maintenance, servicing and insurance against damage) and benefits due to the gains for the avoided bill costs, the incentives and the sold electricity;
- b. analysis of cash flows;
- c. evaluation of the economically effective and ineffective roofs;
- d. estimation of the energy cover factor related to the results of the economic analysis;
- e. sensitivity analysis for the most significant physical and economic parameters.

If the term relative to the investment prevails in the arithmetic comparison, the investment under consideration shall not be advantageous from a strictly financial point of view. If we want to represent this concept in a simplified way, the earning  $G$  for a given pluriannual investment allowing a return  $R$  in the face of a series of costs  $C$  is given by this simple relation [1], [12], [13]:

$$G = R - C \quad (1)$$

This relation would be valid only if the economic solution had an instant duration. In reality, there is always a temporal deviation between the initial investment and the subsequent cash flows available according to particular time schemes. As a consequence, the comparison shall be carried out by using correlation coefficients which equalize the value of the money available over different times.

### 2.3.1. Net present value (NPV)

Suppose that an investment  $I_0$  originates in the future years some positive or negative cash flows which are produced in the various years  $j$  of duration of the investment itself. These cash flows are:  $FC_1$  in the first year,  $FC_2$  in the second year,  $FC_j$  in the  $j$ -th year. To make this comparison, the cash flows must be “updated”, each one referred to the year in which it shall be available, multiplying it by the relevant discount factor [13]:

$$\frac{1}{(1 + Cc)^j} \quad (2)$$

Where,  $Cc$  is the cost of the capital given by the relation  $Cc = i - f$ , difference between the estimated interest rate “ $i$ ” and the rate of inflation “ $f$ ”. Therefore, by Net Present Value it is meant the difference between the sum of the  $n$  discounted cash flows ( $n$ =years of duration of the investment) and the initial investment  $I_0$  [14]:

$$NPV = \sum_{j=1}^n \frac{FC_j}{(1 + Cc)^j} \quad (3)$$

When the NPV results to be positive, it means that - at the end of life of the investment - the discounted cash flows produced will have given greater returns than the cost of the initial investment and therefore the erection of a plant is convenient from a financial point of view; vice versa when the NPV is negative [14].

### 2.3.2. Economic indicators

- a. *Internal Rate of Return (IRR)*: It is the value of the cost of the capital  $Cc$  for which the NPV is equal to null and it represents the profitability of the investment whose suitability is being evaluated. If the IIR exceeds the value of  $Cc$  taken for the calculation of the NPV, the considered investment shall be profitable. On the contrary, if the IIR resulted to be lower than the return  $R$ , the investment would have to be avoided. Besides, when choosing among possible alternatives of investment with equal risk, that one with the higher IIR must be chosen [13].
- b. *Discounted Payback (DP)*: If “ $n$ ” is the number of years foreseen for the investment, the number of years “ $N$ ” after which the NPV is null represents the discounted payback. If  $N < n$  the investment shall be favorable, the opposite when  $N > n$  [1] [13].

- c. *Simple Payback (SP)*: The payback time is defined as the ratio between the initial investment and the expected cash flow considered fixed in amount and periodically scheduled[1], [13], [15]:

$$TR = \frac{I_0}{FC} \quad (4)$$

This economic indicator is very much used but it can give too optimistic indications since it doesn't take into account the duration of the investment and of the cost of the capital.

### 2.3.3. Economic considerations on PV installations

The revenues obtained by connecting the plant to the grid during the useful life of the plant itself (usually 25 years) are constituted by the following elements[1], [13], [15]:

- incentive tariff on the produced energy (supplied for 20 years);
- non-paid cost for the energy not drawn from the grid but self-consumed and possibly sold (sale contract).

The installation of a PV plant requires a high initial investment but the running costs are limited: the fuel is available free of charge and the maintenance costs are limited since, in majority of cases, there are no moving parts in the system. These costs are estimated to be about from 1 to 2% of the cost of the plant per year and include the charges for the replacement of the inverter in the 10th-12th year and an insurance policy against theft and adverse atmospheric conditions which might damage the installation.

In spite of the technological developments in the most recent years, the costs for the erection of a plant are still quite high, especially when compared to electric generation from fossil sources and in some cases also in comparison with other renewable sources.

### 2.4. Solar energy calculations

One single solar panel from type standard 150 Watt / 24 volts can deliver a power of 150 Watt per hour, considering full sunshine. Knowing that the sun shine vary during the day, the effective sun power of one day is equal from 4 to 6 hours of a maximum measured at midday. Since this maximum at midday is not the same every day it should be taken into consideration that more or less heavy cloud reduces the possible power. The electrical power is stored into batteries, similar to the one used in cars.

*Example*: One solar panel of 150W/24V produce between 150W x 4h = 600 Wh and 150W x 6h = 900 Wh. One battery of 12V/110Ah has a capacity of 12V x 110Ah = 1320 Wh

For technical reasons, it is not recommended to empty a battery more than 70%. The usable capacity of this type of battery is around 924 Wh, what match to the produced electrical energy of 600Wh to 900Wh. We are offering 24V-systems, using 2 batteries with 12V/110Ah. Using an inverter 24V to 230V connected to the batteries, it is easily possible to get a power source of 230V driving different types of electrical appliances like a fan, energy saving lamps or a television.

*But notice*: There are different types of inverters. The type of inverter advised has an output of pure sinus. Using them will avoid troubles that can occur on critical devices like television or personal computers. If the inverter has a modified sinus output or (worst case) a rectangular output, a significant part of the stored electrical energy will be wasted and on long-term running critical devices may damage.

With the stored power of 600 Wh to 900 Wh (one solar panel, see example above), it is possible to use the following devices:

- 4 energy saving lamps 11W, time of use 4-6 hours (4x 11Wx 4h = 176 Wh)
- 1 fan 75W, time of use 3-5 hours (1x 75Wx 3h = 225Wh)
- 1 television 100W, time of use 2-3 hours (1x 100Wx 2h = 200Wh)

Total consumption = 601 Wh. We recommend the usage of two solar panels to get a buffer capacity in case of less sun.

The main thing is to get an idea of the electrical power needed for the devices that are supposed to be powered by solar energy and also an idea of the duration of use of each device. With this two information, it is possible to calculate the size of the solar panel required to obtain good results. On most electrical devices, the power consumption is written on it and these specifications are based on one hour of usage.

### 3. Datasets

To support Research & development in the country and promoting Start-ups focused on technology and innovation, a weighted deduction of 150% of expenditure incurred on in- house R&D is introduced under the Income Tax Ac. In addition to the existing scheme for funding various R&D projects have been funded through new scheme like Support International Patent Protection in Electronics & IT (SIP-EIT), Multiplier Grants Scheme (MGS).Geographic parameters including daily average energy incidents, the duration and availability of sunshine and also solar power density across different geographic locations, influence the scope of solar photovoltaic deployment. Table 3 provides facts on solar radiation in India[16][17].

Table 1. All-India Cumulative Generating Capacity (*As on 31st March 2012*)[18]

Category	Hydro	Thermal	Nuclear	RES (MNRE)	Total
Centre	9,085.40	45,817.23	4,780.00	0.00	59,682.63
State/UTs	27,380.00	55,024.93	0.00	3,513.72	85,918.65
Private	2,525.00	30,761.02	0.00	20,989.73	54,275.75
Total	38,990.40	131,603.18	4,780.00	24,503.45	199,877.03

Table 2. Table Showing Household Access to Energy[20]

Energy Source	61 <sup>st</sup> Round 2004-05 (Rural)	61 <sup>st</sup> Round 2004-05 (Urban)	61 <sup>st</sup> Round 2004-05 (Total)	66 <sup>th</sup> Round 2009-10 (Rural)	66 <sup>th</sup> Round 2009-10 (Urban)	66 <sup>th</sup> Round 2009-10 (Total)
Electricity	54.9	92.3	65.2	67.3	93.9	75.5
LPG	8.6	57.1	21.9	15.5	66.2	31.2

Though government subsidies, lower interest rates on loans and the significant reduction in solar panel prices are encouraging there are more challenges that need to be addressed including optimal solution design for various energy management scenarios, seamless integration with other renewable energy technology (RET) solutions and optimal configuration of solar photovoltaic panels as well as appropriate storage and space requirements[16], [19].

#### 3.1. Ministry of new and renewable energy (MNRE)

Table 3. Commercial Energy Supply Trends from Domestic Production[22]

Item	2000-01	2006-07	2011-12	2016-17	2021-22
	<i>Actual</i>	<i>Actual</i>	<i>(Prov)</i>	<i>Projected</i>	<i>Projected</i>
Coal	130.61	177.24	222.16	308.55	400.00
Lignite	6.43	8.76	10.64	16.80	29.00
Crude Oil	33.40	33.99	39.23	42.75	43.00
Natural Gas	25.07	27.71	42.79	76.13	103.00
Hydro Power	6.40	9.78	11.22	12.90	17.00
Nuclear Power	4.41	4.91	8.43	16.97	30.00
Renewable Energy	0.13	0.87	5.25	10.74	20.00
Total ( <i>Domestic Commercial Energy</i> )	206.45	263.28	339.72	481.84	642.00
Non-commercial Energy 1	136.64	153.28	174.20	187.66	202.16
Total	343.09	416.56	513.92	669.50	844.16
Imp { Coal	11.76	24.92	54.00	90.00	150.00

Petroleum Products	77.25	98.41	129.86	152.44	194.00
LNG	0.00	8.45	12.56	24.80	31.00
Hydro power	0.00	0.26	0.45	0.52	0.60
Total Net Imports	89.01	132.04	196.87	267.76	375.60
Total (Commercial Energy )	295.46	396.32	536.59	749.60	1,017.60
(growth over previous 5 years)					
Total Primary Energy	432.01	549.60	710.79	937.26	1,219.76

To encourage the usage of alternative and renewable energy sources, the MNRE provides the following support under the JNNSM scheme. The MNRE announced its support for 400 telecom towers using solar photovoltaic technology. TRAI's mandate requires that telecom companies should use renewable sources of energy to power at least 50% of rural telecom towers and 20% of urban telecom towers by 2015. By 2020, the telecom companies have to convert 75% of rural towers and 33% of urban towers to run on hybrid power. The MNRE's recent mandate to convert a minimum of 50,000 towers to solar photovoltaic technology immediately is another step towards ensuring compliance for the adoption of clean energy. Several proposals from the government have been rolled out for solar powered telecom sites such as Bharat Sanchar Nigam Limited's (BSNL's) tender for 15 telecom towers in Bihar and the Department of Telecommunications' proposal for 2,200 telecom towers for security networks[16], [21].

Table 4. Cost of Power for Various Renewable Energy Sources[20]

	Estimated initial capital cost (₹ in crore/ MW)	Estimated cost of electricity generation (₹ / kWh)
Small Hydro Power	5.50-7.70	3.54-4.88
Wind Power	5.75	3.73-5.96
Biomass Power	4.0-4.45	5.12-5.83
Bagasse Cogeneration	4.20	4.61-5.73
Solar Power	10.00-13.00	10.39-12.46

The Energy Practice at telecom sector has in-depth understanding of Indian Power Sector and has focus on Energy Management, Renewable Energy, Services and Smart Grid. We have been associated with private sector utilities, large corporate & MNCs to support them in areas of strategy, market assessment and strategic performance improvement [16], [21].

Table 5. Estimated Renewable Energy Potential (MW) (As on April 2013)[3], [23]

Sl.No.	Resource	Estimated Potential (MW)
1	Solar Power(30-50 MW/sq. km)	100000
2	Wind Power (At 80 m. height)	100000
3	Small Hydro Power (up to 25 MW)	20000
4 i)	Bio-Power: Agro-Residues	17000
4 ii)	Bio-Power: Cogeneration - Bagasse	5000
4 iii)	Waste to Energy: Municipal Solid Waste to Energy	2600
4 iv)	Waste to Energy: Industrial Waste to Energy	1280
	TOTAL	245880.00

#### 4. Results and discussion

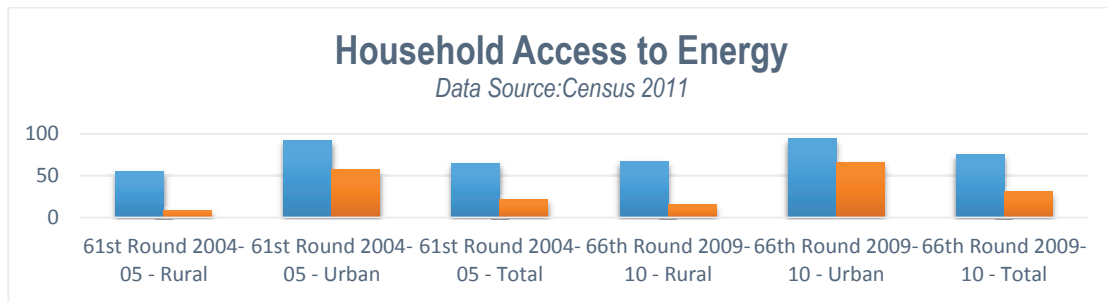


Fig. 2. Household Access to Energy in India [11][10]

Figure 2. Census of India 2011 report reveals the fact that the energy accessibility to household in India for the year 2004-05 and 2009-10 in the rural and urban areas has been meagre. There is lot; In other words, we can assume that in total there is an apparent gap between rural and urban access to household energy resources which impulses the apparent load on energy resources in urban areas and concurrently reducing the rural energy supply.

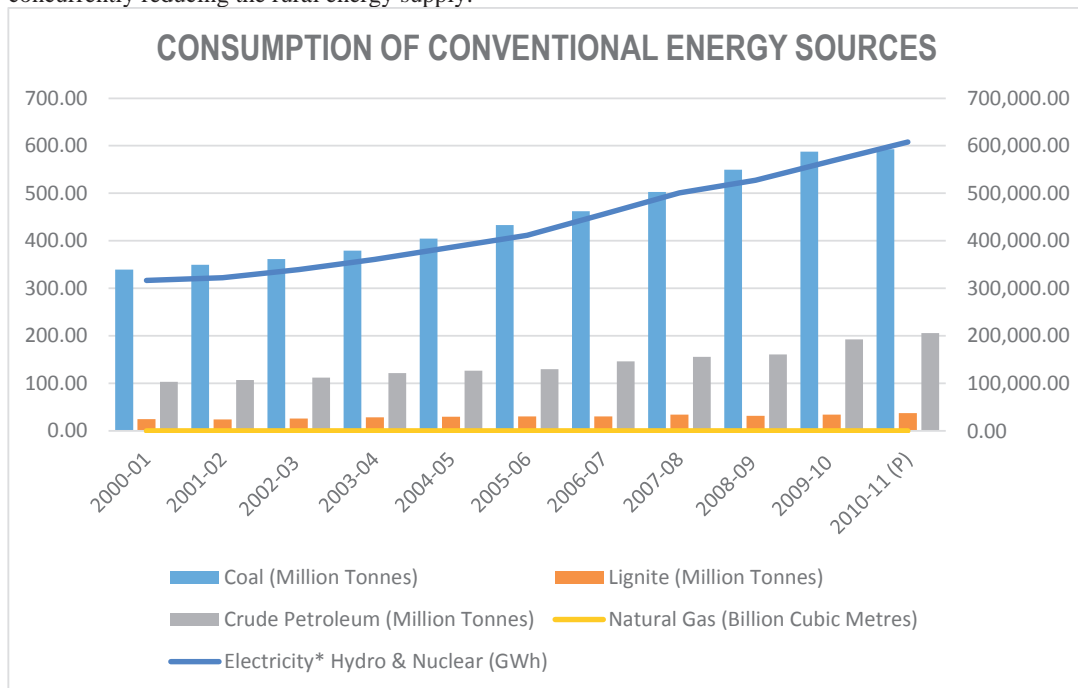


Fig. 3. Consumption of Conventional Energy Sources in India [10][11]



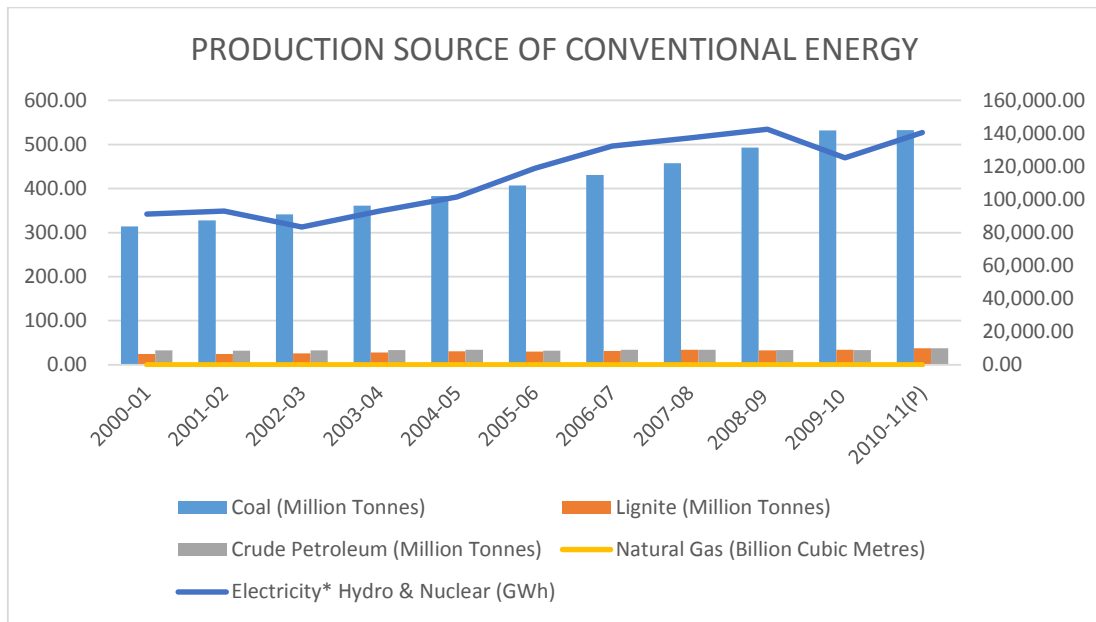


Fig. 4. Productions of Conventional Energy Sources in India [10]

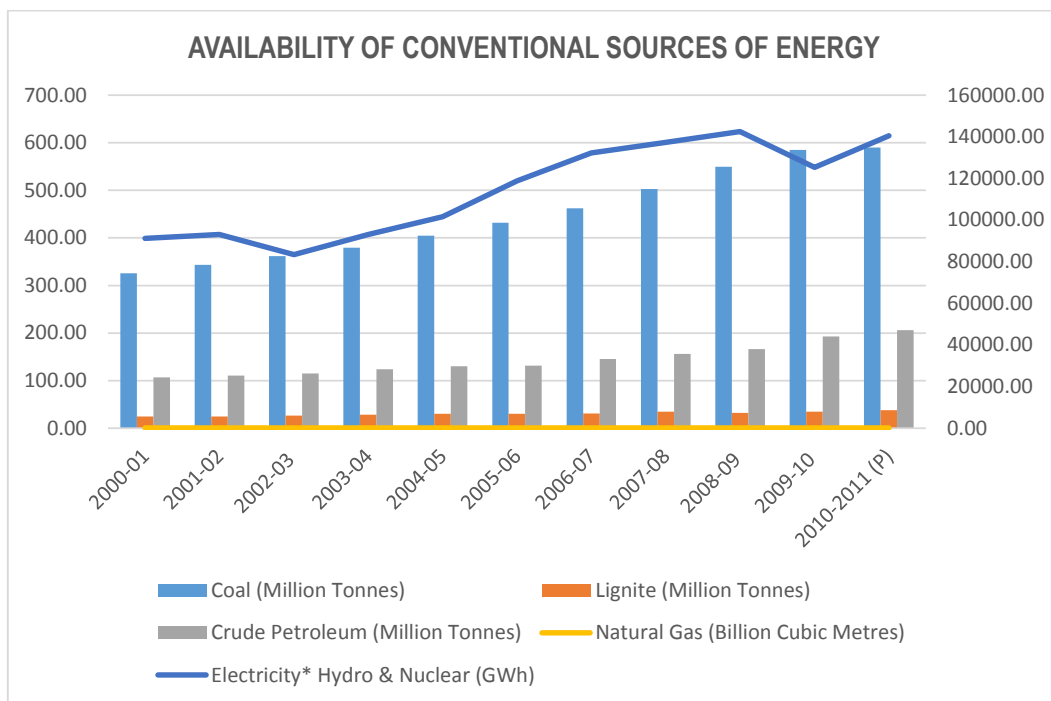


Fig. 5. Availability of Conventional Energy Sources in India[10], [11]

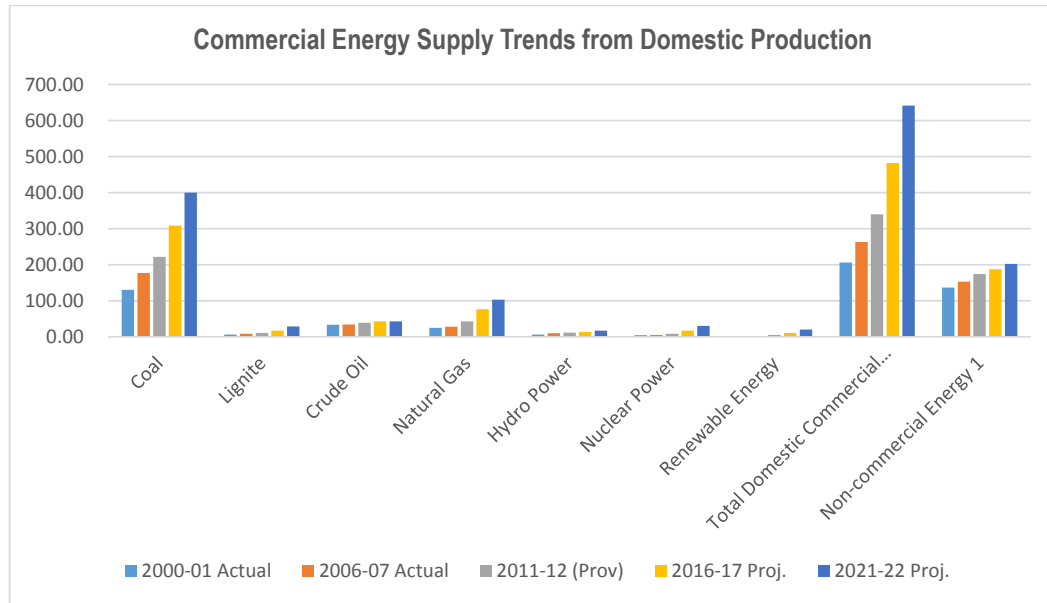


Fig. 6. Trends in supply of primary commercial energy in India from domestic production in India[10]

Figure 3. Reveals the fact about the consumption of conventional energy sources. The above diagram visualizes that the coal is serving as the major source of the energy since 2000 and its consumption (in million tonnes) has also increased exponentially from 2000 to 2011. Subsequently the coal, the petroleum is serving as the ancillary source of conventional energy and its consumption trends also show the exponential growth. The above histogram projections replicate and forecast that coal and petroleum are highly susceptible to be vanished in the coming years. These are lying on the edge of highly unstable surface. In analogous to these the electrical consumption patterns have also taken mileage towards the exponential pattern. This consumption trends connotes the importance of swapping conventional energy towards the renewable energy usage. Furthermore, this also illustrates the actual escalation trends of energy consumption in recent decades which will lead to numerous types of adversities in upcoming years.

Figure 4. Unveils the fact about the conventional sources of energy and has fluctuating trends in terms of production sources of conventional energy. The above diagram infers that the coal is serving as the major source of the energy production since 2000 and its production capability has also amplified in slightly exponential pattern from 2000 to 2011. In similar to these the electrical production from the Hydro and Nuclear has also taken mild stretch towards the exponential pattern. This production trends connotes the prominence of exchanging conventional energy generation towards the renewable energy production.

Figure 5. Tells the fact about the availability of conventional energy sources. The above diagram encapsulates the fact that the coal is serving as the major source of the energy since 2000 due to its exploration of new excavation at several identified places during 2000 to 2011. After coal, the petroleum is serving as the ancillary source of conventional energy and its availability shows the growth during the period of 2000 to 2011 due to advancement of exploration technologies. In synoptic condemnation we can forecast that coal and petroleum are highly susceptible to be vanished in the coming years due to escalation trends of overhead energy depletion in recent decades, and exploration

of existing reserves of these resources to the maximum extends.

Figure 6. Illustrates the commercial energy supply trends of domestic production which signals the fact about the conventional sources of energy that has exponential growth. The above diagram also endorses that the coal is serving as the major source of the energy production sources since 2000 and its energy supply capability has to be also amplified in exponential form for the upcoming years. In relation to these the non-commercial supply has to be also taken stretched inline to the same exponential pattern. These supply trends presages the eminence of commercial conventional energy with the non-commercial energy.

A typical telecom tower has an energy requirement in the range of 3-5 kW. Various technology solutions are available for powering telecom towers but success of each of the available technology depends on multiple factors like capital expenditure, operating cost, reliability etc. While there are complex technologies like fuel cells available, viability in Indian context becomes a question. In India, solar and wind have been widely used in various distributed generation applications and have been successful in the past.

Telecom towers powered by energy sources other than electricity board or diesel are slowly gaining prominence in India. Slowly telecom tower companies have now started adopting hybrid power sources to meet their energy demand. Telecom towers companies are increasingly looking at renewable energy as an intermediate solution which could help reduce dependence on liquid fuel. Some tower sites have successfully combined conventional and alternate energy to overcome the load shedding issues.

Renewable energy has evolved considerably over the last couple of years. In this editorial we have explored potential that might tilt the balance in favour of telecom towers powered by renewable energy. SWOT Analysis predicts the potentials of renewable in establishing the Green Networks in Indian scenario. The several parameters were taken into account for giving the final verdict for implementing the concept. Considering all the above discussed conditions and aspects we can resolve that the telecom industry in India traditionally used grid power as the primary source and diesel generators as the secondary source or as backup to grid power.

## 5. Conclusions

The evaluation of the real energy and economic effectiveness of the PV systems for reaching ambitious targets of the European Union in the energy field is of paramount importance for addressing decision makers towards different options of financial supports. In the meantime, scientists have developed much experience in the above field but still now it misses a simple methodology for assessing the effectiveness of the PV systems in urban contexts where the complexity of the problem has to cope with the need to simulate PV systems in reliable, fast and effective ways. The shown methodology has the above requested features and permits testing the level of integration of the photovoltaic technology in urban areas.

The methodology was applied for the percentage of coverage of the electricity demand and the economic feasibility of grid-connected photovoltaic systems installed on the roofs of buildings. The obtained results showed the difficult to size the PV systems in big urban contexts in a proper and effective way and point out the suitability of the tool for energy planning of the above systems. Considering energy and economic parameters the cover factor decreases. The possibility to identify situations where the economic feasibility of investments is not convenient is an important feature of the method that can help decision makers to select effective alternatives in energy planning procedures. The householder's perspective on PV investment is also related to energy storage and policies regulating self-production. Both aspects need an accurate analysis: due to the load mismatch some amount of PV electricity may be exported to the grid because the electrical demand is temporarily lower than production, whereas a consumption which is higher than production and/or that does not match the available PV generation which will require to be supplemented by the public grid electricity. The energy self-sufficiency is one of the factors which may determine an economic advantage upon careful analysis of the actual costs for the devices. Similarly, an energy policy that supports the PV electricity consumed penalizes the energy exported to the grid with a reduced incentive value.

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